CARBON NEUTRALITY IN MAKERSPACES:

CIRCULAR MAKERSPACE EVALUATION TOOLKIT (CMET)

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ABSTRACT: The practices of making and learning by doing remain a cornerstone of education today. In the context of carbon neutrality, we extend a typical "making" stage into "sustainable making" and "meaningful making" on colleges campuses for the procurement process, material selection, students' awareness, pedagogical design, and makerspace system. The goal of the study is to offer a shared sustainable vision with short-term solutions and long-term goals by applying circular design methodology and human-centered design to reduce the carbon footprint of makerspaces. We use MIT as a testbed to prototype carbon-neutrality-related experiments to evaluate concepts and validate ideas. The Circular Makerspace Evaluation Toolkit (CMET) created in this paper will not only empower future generations of teachers, professionals, policymakers and community leaders, but scale to industry and society. CMET breaks down the evaluation process into five stages and ten environmentally responsible elements to quantify, measure, and celebrate the value of circular makerspaces to users/makers, and inspire them and other makerspaces around the globe to view "circular" as a new creative currency of carbon neutrality, thus motivating users/makers to create feasible plans, change their behaviors, cultivate sustainable maker culture and, through their makerspaces, make an invaluable contribution to the Circular Economy.

Keywords: Carbon Neutrality, Sustainability, Circular Economy, Circular Makerspace

1. INTRODUCTION

To avoid the worsening effects of climate change, efforts toward carbon neutrality have become increasingly critical for the whole world. Carbon neutrality, the state of net-zero carbon emissions, describes the balance of carbon emissions and carbon sequestration. Carbon neutrality is one strategy to reduce the impact of global warming. As efforts toward carbon neutrality intensify, we expect to see their impact on industries, academic fields, and society. In response to the discourse around carbon neutrality, higher education has developed curricula that can cultivate understanding of the environmental and economic trade-off with social and moral awareness to tackle this systemic global issue (Sibbel, 2009; Adrian Smith & Light, 2017). Academics are adapting to embrace the challenges of sustainable development for education in the 21st century (Everett, 2008).

Massachusetts Institute of Technology (MIT) has been a pioneer in this area by applying the latest technology, scientific approach, engineering, data, and human-centered design. In 2013, Dr. Julie Newman and her team established the MIT Office of Sustainability (MITOS). The mission of MITOS is to *"transform MIT into a powerful model that generates new and proven ways of responding to the unprecedented challenges of a changing planet via operational excellence, education, research, and innovation on our campus"* (MIT Office of Sustainability, 2013). Many other universities have also initiated activities related to sustainability. Rochester Institute of Technology's Industrial Design Department created and experimented with carbon footprint assessment tools (Lobos et al., 2013) and considers innovative approaches to better integrate the awareness of carbon neutrality and sustainability into design education. The government is also interested in makerspace and its relationship with sustainable city development (Sleigh et al., 2015).

The purpose of this study is to explore, understand, and envision potential solutions by designing a Circular Makerspace Evaluation Toolkit (CMET) that provides a series of guiding principles, context-driven frameworks (Table 1), actionable roadmaps, and interactive tools to transform makerspaces into “circular” makerspaces (Prendeville et al., 2017), sustainable places, to reduce their carbon footprints and position them as important educational touchpoints for teaching and sharing the knowledge of carbon neutrality. In addition to reviewing literature on carbon neutrality in design education, we used MIT Project Manus (Culpepper & MIT Innovation Initiative, 2015), MIT D-Lab Workshop (Amy Smith & Yang, 2002), MIT Hobby Shop (MIT, 1937), and an MIT Integrated Design & Management (Kressy, 2014) ID Lab course as case studies to discuss the current carbon neutrality challenges that confront campus makerspaces and design education and their relationships with the Institute’s strategy of sustainability. We conducted field research, interviewing faculty and industry experts from two MIT makerspaces, and professors and teaching assistants from programs and courses to gain an overview of the MIT makerspaces and design education. In addition, we suggest a feasible future blueprint for creating a circular makerspace (Prendeville et al., 2017), a sustainable making environment, to meet MIT’s carbon neutrality goal by 2030. In this paper, we use the term “makerspace” to represent the general concept of workshop space, shop, and fabrication facilities/resources.

2. LITERATURE REVIEW

2.1 CARBON NEUTRALITY IN MAKERSPACES AND DESIGN EDUCATION

Universities play a critical role in the study of carbon neutrality and in helping our world become more sustainable (Howlett et al., 2016). The American College & University Presidents’ Climate Commitment (ACUPCC) was created by twelve college and university presidents in 2006 presenting their shared vision and determination that higher education needs to serve as a leading role model on sustainability and carbon neutrality not only to their students but also to society. Since then, ACUPCC has included more than 598 universities focusing on a carbon commitment (Interface, 2014). As carbon neutrality challenges are complicated and systemic, the universities need to take proactive steps to raise students’ greater awareness of moral and social responsibilities (Sibbel, 2009; Adrian Smith & Light, 2017) and reach the goal of sustainability through their action (Kopnina, 2019). One methodology is a “whole-of-university” approach, an integrated and circular design methodology, to address carbon neutrality issues by connecting research, campus operations, and curriculum explicitly (Mcmillin & Dyball, 2009). Another study researched how makerspaces can help cultivate more sustainable developments (Adrian Smith & Light, 2017).

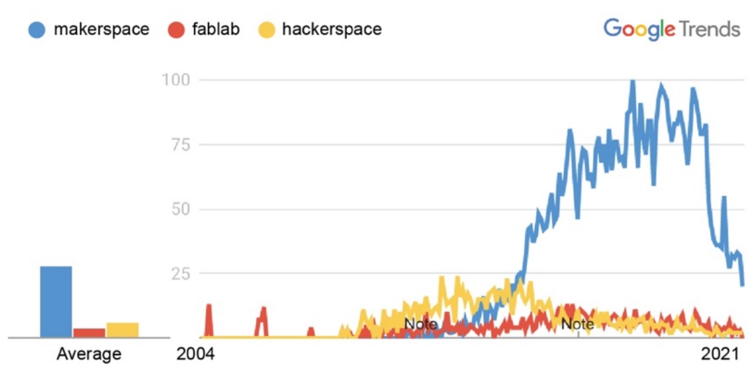

Figure 1. The number web search for the words e.g., makerspace from 2004 to 2021 in the United States (Source: Google Trends)

Makerspaces have drawn interest in the past decades in the United States (Fig. 1), playing a critical role on campus to meet the needs of students and requirements of universities to cultivate the culture of making among communities. As sustainability issues become a worldwide trend, universities consider every key touchpoint and experience on campus, including makerspaces. Take MIT as an example. In 2016, the Institution initiated Project Manus (Culpepper & MIT Innovation Initiative, 2015) that aimed to upgrade the hardware and software of campus makerspaces by taking carbon neutrality into consideration. In 2019, MITOS initiated a program to issue a safe and sustainable lab and makerspace certificate (MIT Office of Sustainability, 2021) by providing a set of helpful checklists, well-thought-through considerations, professional suggestions, and experts' help. To meet the goal of carbon neutrality by 2030, some universities' demand for environmental-friendly product development in makerspaces includes equipment, machines and tools for prototyping, and material procurement, recycling, and storage (Klemichen et al., 2018) They also look to apply new frameworks to evaluate the sustainable outcome (Rusinko, 2010; Argento et al., 2020). Thus, carbon neutrality in makerspaces and design education has become popular and raised people's interest.

2.2 CIRCULAR ECONOMY AND DESIGN APPROACH

Since makerspaces and design education are interwoven as parts of a complex ecosystem (De los Rios & Charnley, 2017), we leveraged circular design approaches and mindsets as inspired by the Circular Design Guide (IDEO & Ellen MacArthur Foundation, 2017) and other relevant materials (Straten et al., 2021; Crul et al., 2019; Deloitte, 2016; Chapman, 2009). In the study, we introduce and integrate the concept of a "circular" makerspace (Heinrich & Stefanovska, 2020; Metta & Bachus, 2020; Prendeville et al., 2017) to a typical makerspace on campus. It can not only facilitate people's awareness of carbon neutrality and their environmentally responsible action in makerspaces (Mcmillin & Dyball, 2009; Adrian Smith & Light, 2017) but also help measure the contribution of circular makerspaces to the Circular Economy in a scientific way.

Ellen MacArthur Foundation (EMF) collaborated with IDEO to launch The Circular Design Guide in 2017 by providing activities and methods over four phases: Understand, Define, Make, and Release (IDEO & Ellen MacArthur Foundation, 2017). The Understand phase is to gain fundamental knowledge, essential skills, and insights around circular design solutions and their background information to transform peoples' mindsets from linear to circular thinking. The Define phase is to explore the unknown challenges by identifying problems through the lens of circular perspectives. The Make phase is to understand the key stakeholders' pain points across their user journeys and then to leverage brainstorming to fill out high- potential opportunities preparing for the next step of selected concept development. The Release phase is to test the selected concepts on the market to constantly gather users' feedback. The design of concepts will keep evolving through the prototyping process; the business model, service components, and organization will be transformed circularly.

EMF also partnered with MITOS (Ellen MacArthur Foundation, 2020) to apply a circular design approach, build data infrastructures to capture the right information, and collaborate with a partner specializing in waste to solve waste problems on campus by: 1. reducing contamination among the waste, 2. decreasing volume of the landfill by recycling material effectively, 3. maintaining soil health on campus, and 4. changing people's behavior and cultivating new rituals of waste management. The Circular Economy and circular design approach enable us to reframe the design process, tools and framework from linear to circular thinking to better implement them into the circular makerspace.

3. CASE STUDY: MIT MAKERSPACE

One of MIT's educational missions is "learning by making/doing." The importance of "making" can be seen from the number of MIT makerspaces, including not only the four we are examining, but dozens of other featured makerspaces. Each makerspace offers access to all types of machines, prototyping tools, materials, space, training programs, and courses relevant to making at MIT. The estimated total area of the MIT makerspaces is over 130,000 ft^2 (12,077 m^2) across over 40 design/build/project spaces (MIT Facts, 2020). Since making is a cornerstone of MIT, the Institute initiated Project Manus in 2016 as part of its Innovation Initiative that aimed to upgrade the hardware and software of campus makerspaces, establish innovative academic maker systems for the next generation, and cultivate student maker communities. However, research has shown that there is still much room for improving the carbon footprints of most MIT makerspaces by implementing carbon neutrality ranging from planning to environmentally responsible action. Helping makerspace users understand the value of sustainability by providing a clear vision of carbon neutrality is the first step (Klemichen et al., 2018).

3.1 DEMOGRAPHICS

We leveraged the MIT Maker Survey (Culpepper & MIT Innovation Initiative, 2015) to inform us of the demographics of makerspace users and their behaviors, needs, and pain points. The survey received a 17% response among the MIT community, which consisted of 22% of undergraduates and 13% of graduate students responding in academic year 2015. The result showed that 47% of MIT students spend more than five hours building, making, or creating during a typical week. Since they stay and work in makerspaces for a long time, 58% of them want to have basic and intermediate makerspace training to teach them how to use simple and complex tools and technologies. Another finding reveals that 22% of students spent below $50 of their own money on the resources, raw materials, and tools in one academic year. These findings indicate that MIT makerspaces can provide most of the needs of students. They don't need to worry about materials and tools for their projects since 19% of them don't even spend any money during one semester.

Regarding areas of students' interest, 62% of them solve the challenges connected to software, code, and programming, whereas 41% are interested in electronics, Arduino, 3D printing, rapid fabrication, and prototyping. Also, 36% use makerspaces to work on hardware and machining-related topics. The result showed that students have a diverse range of interests in woodworking, product design, UI/UX, web design, metalwork, soldering, sculpting, photography, culinary arts, and painting. Makerspaces can support them with tools, machines, people (e.g., technical experts, shop managers), and maker community. The research also reveals that over 50% of MIT students are willing to take basic training to learn how to use simple and complex tools, machines, and software in makerspaces, from which we can assume that this could be a great opportunity and entry point to teach and implement the key concepts, the essential knowledge, and applicable methodologies of carbon neutrality in the MIT maker community to realize the goal of building a sustainable makerspace and culture on campus by 2030.

3.2 QUALITATIVE APPROACH: EXPERT INTERVIEW

In the study, we conducted seven 30-min virtual expert interviews, paired with two field trips at MIT D-Lab Workshop and MIT Hobby Shop to acquire first-hand perspectives on the makerspace (Fig. 2). We interviewed three faculty members from D-Lab Workshop and MIT Hobby Shop, one associate director from MIT Project Manus as well as one lecturer and two teaching assistants from MIT Integrated Design & Management, to gain a better understanding and overview of MIT makerspaces. We discussed the topic of carbon neutrality in makerspaces on campus, including how makerspaces are managed and operated currently, their general material procurement process, challenges of organizing the materials, machines, people, and systems, as well as their approaches to collaborating and coordinating with other lecturers, courses, and departments.

From expert interviews, we gained five key takeaways: 1. Managers with diverse interpretations of sustainability and carbon neutrality vary in their awareness of carbon neutrality among MIT makerspaces. Most don't know that MITOS provides Sustainable Makerspace Certification (MIT Office of Sustainability, 2021) and services to help build a more sustainable and eco-friendly working environment. 2. There is no standard material procurement process. Normally, students bring their materials to makerspaces. Makerspace managers also help them purchase materials based on their previous experience, intuition or discussions with lecturers prior to courses. 3. Most MIT makerspaces have very limited storage areas for materials. 4. Each MIT makerspace is relatively independent in terms of shared resources, operation, spatial layout, and community culture. 5. The top priority of MIT makerspace is to make tools, machines, and resources (e.g., training program, material) accessible to MIT students and communities. One interviewee shared his view that the MIT makerspace's goal of carbon neutrality and sustainability should be included in MIT's mission at the Institution level.

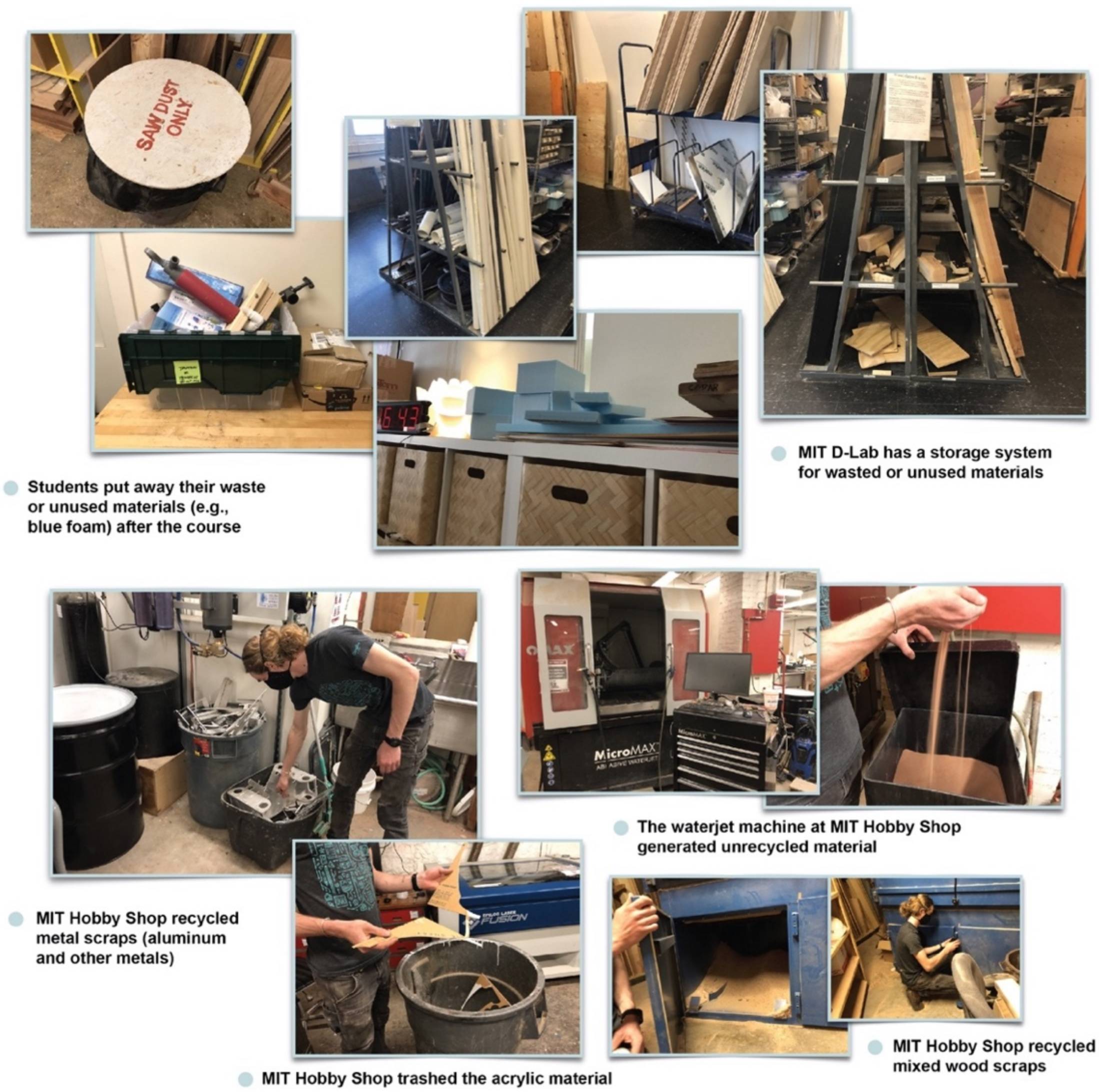

Figure 2. Field trip observation at MIT D-Lab Workshop and MIT Hobby Shop

3.3 QUANTITATIVE APPROACH: DATA ANALYSIS

Using MIT Maker Map (Fig. 3) and MIT DataPool (Fig. 4), we analyzed the MIT makerspaces' electricity consumption data and material lifecycle (waste data) in year 2019 to summarize the result and suggest future research in terms of data collection and focus.

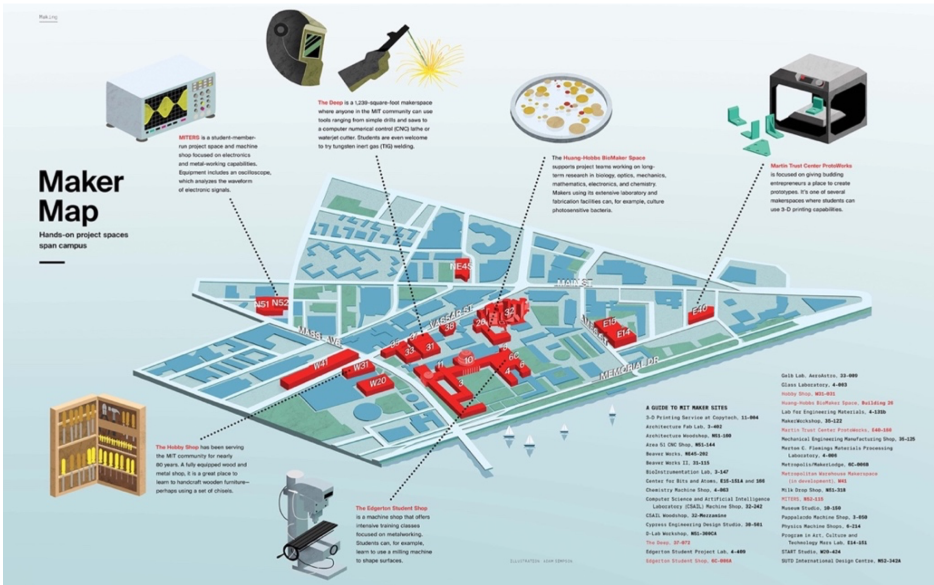

Figure 3. MIT Maker Map: hands-on project spaces span campus (Illustration: Adam Simpson)

Electricity Consumption: Using MIT DataPool, we analyzed the electricity (kWh) consumption of selected buildings that contain MIT makerspaces in 2019. Building 32's (CSAIL Woodshop) consumption is significantly higher than that of others. Besides reading the data of electricity, we also consider the area of the building to calculate per square footage of energy consumed. It shows that the ratio of consumption of Building 31 (Beaver Works II), Building 38 (Cypress Engineering Design Studio), Building W31 (Hobby Shop), Building 37 (The Deep), and Building E14 (Program in Art, Culture, and Technology Mars Lab) are relatively high. However, the result cannot precisely reveal the actual energy consumption of makerspaces as the selected buildings consist of labs, offices, and mixed spaces. We also need to understand the number of students/participants using makerspaces as well as their frequency and time of using them.

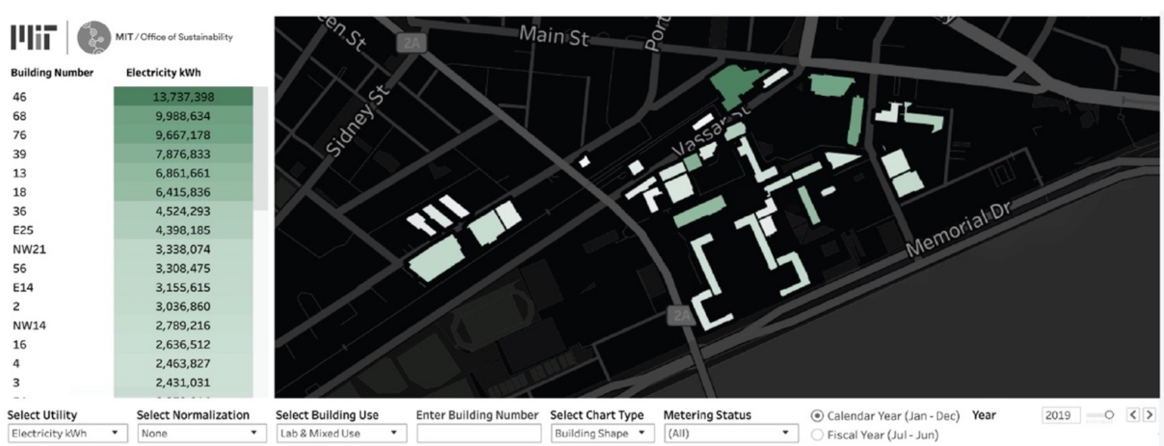

Figure 4. MIT Building-level utilities (Labs & Mixed Use): electricity (kWh) consumption in 2019 (Source: MIT DataPool)

Material Lifecycle: The material lifecycle can provide another informative aspect for us to understand carbon neutrality of makerspaces. Lifecycle conveys holistically the journey of materials: how we procure, reuse, recycle, repair, and repurpose them. MIT provides many channels for researchers and students to access the waste-related data and information of used material including MITOS, Department of Facilities, MIT Green Lab, Rheaply, MIT Waste Alliance, and MIT Solve. Students can take a fundamental online course (e.g., Responsible Waste Disposal Practices) from MIT Atlas Service Center. In addition, in 2019, MITOS collaborated with the Department of Facilities to design a Request For Proposal (RFP) offering, a campus-wide waste management service, to experiment with a new systemic approach to solve material waste issues. In the study, we focused on and analyzed the campus material waste data. According to the MIT DataPool's Material Collected and Removed Data, the majority of the waste by category comes from non-housing waste (33%) and recycling (31%). The data includes the waste from makerspaces. Due to the current setup of the data capture, it is relatively difficult to distinguish the percentage actually generated from makerspaces. We assume the material waste from makerspaces is significantly low compared with housing waste, yard waste, and food waste.

Future Data Collection and its Challenge: For further research of quantitative data analysis, we suggested MITOS collaborate with MIT DataPool to establish a set of robust systems and mechanisms with carbon neutrality criteria to document makerspaces' energy consumption, manage materials lifecycle and its efficiency (storage/recycle/waste), and build an optimized and flexible workflow adjusted to different types of makerspaces through a scientific approach.

4. CIRCULAR MAKERSPACE EVALUATION TOOLKIT (CMET)

The current MIT DataPool platform lacks comprehensive data specifically for makerspaces including energy, water, waste, and materials procured. MITOS is in the process of developing the Sustainable Maker Space Certification to create a well-thought-through checklist for MIT makerspaces. Thus, the value of this study lies in designing CMET (Table 1) to build an applicable framework and establish suggested high-level principles to help decrease the carbon footprint in MIT makerspaces. Part of CMET was inspired by Circular Makerspaces-Elements & Levels (Makerspace Adelaide & Government of South Australia Green Industries SA, 2020). By applying CMET, we want to quantify, measure, and celebrate the value of circular makerspace to users/makers, and inspire them and other makerspaces around the globe to view "circular" as a new creative currency of carbon neutrality, thus motivating users/makers to create feasible plans, change their behaviors, cultivate sustainable maker culture, and make an invaluable contribution through their makerspaces to the Circular Economy.

CMET breaks down the evaluation process into five stages (Table 1) from short-term goals with low cost for internal teams to long-term strategies with high investment in external partners: Establish, Enter, Engage, Empower, and Envision. The Establish stage is the very first step of any initiated circular designs or concepts. It is an entry point of CMET. Therefore, most requirements in the Establish stage need to be accessible and approachable to makerspace users and to be technologically feasible and economically viable. The Enter stage is built on the fundamental part of the Establish stage to enhance its core concepts and extend and explore some of the selected ideas that makerspace managers and users want to emphasize to clarify the content and experiments before the next stage. The Engage stage is to get people involved outside the makerspace and to get the resources, material, funding, and talent the makerspace needs at the individual level. It is relatively critical in CMET since it serves as a stepping stone to connect the previous stages and pave the path for the next two stages. The Empower stage is to create advanced and sophisticated circular-design-related ideas, sustainable concepts, and frameworks to assist and improve the current CMET to make it relevant to the context and even influence and lead the industry. The Empower stage also encourages the makerspace to build external relationships at the institutional level. The Envision stage is to make people consider the next step of evaluation criteria beyond the current CMET, which includes applying cutting-edge technology to challenge the future circular makerspace system, its morphed and dynamic structure, and diverse community culture.

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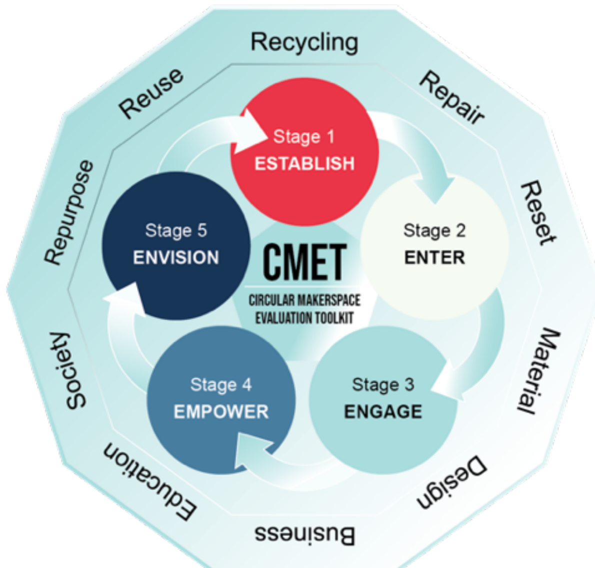
<tr><td>Diagram
Circular Makerspace Evaluation Toolkit (CMET)</td><td colspan="5">
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<tr><td>Goal</td><td colspan="5"><u>Realize Carbon Neutrality in Makerspace on Campus</u></td></tr>
<tr><td>Complexity</td><td colspan="5">Fundamental Entry Point ⟷ Advanced Complex System</td></tr>
<tr><td>Stakeholder</td><td colspan="5">Internal Team ⟷ External Partner</td></tr>
<tr><td>Cost</td><td colspan="5">Low-cost Short-term Goal ⟷ High-cost Long-term Strategy</td></tr>
<tr><td>When
Evaluation Stage</td><td>Stage 1
ESTABLISH</td><td>Stage 2
ENTER</td><td>Stage 3
ENGAGE
(Individual)</td><td>Stage 4
EMPOWER
(Institutional)</td><td>Stage 5
ENVISION</td></tr>
<tr><td>Definition
Evaluation Stage</td><td>Establish stage is the very first step of any initiated circular designs or concepts. It is an entry point of CMET. Therefore, most requirements in Establish stage need to be accessible and approachable to makerspace users as well as to meet the technological feasibility and business viability.</td><td>Enter stage is built on the fundamental part of Establish stage to enhance its core concept and to extend and explore some of the selected ideas that people want to emphasize to clarify the content and experiments before the next Engage stage.</td><td>Engage stage is to get people involved outside the makerspace and to get the resources, material, funding, and talents the makerspace needs at the individual level. It is relatively critical in CMET since it serves as a stepping stone to connect the previous Establish stage and Enter stage and pave the path for the next two stages.</td><td>Empower stage is to create advanced and sophisticated circular-design-related ideas, sustainable concepts, and frameworks to assist and improve the current CMET to make it relevant to the context and even influence and lead the industry. Empower stage also encourages the makerspace to build the external relationships at the institutional level.</td><td>Envision stage is to make people consider the next step of evaluation criteria beyond the current CMET. Envision stage includes applying cutting-edge technology to challenge the future circular makerspace system, its morphed structure, and community culture.</td></tr>
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Table 1. Circular Makerspace Evaluation Toolkit (CMET) diagram and its five evaluation stages

For each evaluated item, we provide both qualitative and quantitative criteria to evaluate its performance connected to its participants. Since CMET is designed for circular makerspaces, we want to use ten environmentally responsible elements: repurpose, reuse, recycle, repair, reset, material, design, business, education, and society to build multifaceted and circular perspectives to consider the makerspace comprehensively from energy, material, business, people, and society. Even though CMET originated from the needs of MIT, it can be applied to other makerspaces beyond the campus. Table 2 shows how we applied CMET to MIT makerspace (recycling element) to illustrate the methods, usage, and benefit of CMET.

Recycling	Stage 1 **Establish**	Stage 2 **Enter**	Stage 3 **Engage**	Stage 4 **Empower**	Stage 5 **Envision**
What Evaluation Item	- Add specific recycle bins for some commonly recycled material for makerspace (e.g., aluminum, metal scrap, wood scrap). - Redesign the wayfinding/communication sign of recycling.	- Besides some big categories of recycling: paper, food waste, composite materials, create more detailed categories for material recycling as well as update the whole campus recycling system.	- Create an evaluation recycling criterion and its system for makerspace preparing for the campus-wide systemic transformation to reach the goal of carbon neutrality.	- Recycling campaigns are initiated by students or makerspaces. It is an expression that maker communities are ready to repurpose and reuse most recycled materials to create new values.	- Envision how do we integrate these recycled materials to the make education system/curriculum and how do we use their recycled material to decorate/fix the environment of makerspaces.
How Evaluation Criteria	- Volumes and types of recycling material collected in makerspace - Recycled kg/tonnes - Decrease CO_2 emissions	- Progress of campus-wide material recycling system - The design and its evaluation plan of the new structure in terms of detailed recycling categories - Recycled kg/tonnes - Decrease CO_2 emissions - Calculate the percentage (%) of purchasing spend per item with a percentage (%) of recycling components	- Number of added recycling criteria for evaluation - Key touchpoint of recycling evaluation flow - Recycled kg/tonnes - Decrease CO_2 emissions	- Number of camping is hosted by makerspaces or students - Story of each camping	- Roadmap of course content integrated with the idea of leveraging the recycled materials - Investment/cost of the new and meaningful pedagogical activities
Who Evaluation Participant	- MIT (university-level) - MIT Office of Sustainability - MIT Department of Facility - Makerspace Manager	- MIT (university-level) - MIT Office of Sustainability - MIT Department of Facility - Makerspace Manager	- MIT (university-level) - MIT Office of Sustainability - MIT Department of Facility - Makerspace Manager	- Makerspace - Students	- MIT Office of Sustainability - Makerspace Manager - Lecturer/Professor - Students

Table 2. Example of applying to CMET in MIT makerspace (Recycling element).

5. SUMMARY

5.1 CONCLUSION AND CONSIDERATIONS

By viewing makerspaces and design education as an ecosystem, we captured and documented comprehensive perspectives for carbon neutrality in makerspaces on campus, and illustrated users' current pain points and their relationships. We applied circular design methodology (IDEO & Ellen MacArthur Foundation, 2017) and human-centered design (IDEO, 2015; IDEO, 2011) to the study, and designed a Circular Makerspace Evaluation Toolkit (CMET), a set of evaluation frameworks and tools for varied scenarios. The toolkit emphasizes raising people's awareness of carbon neutrality, cultivating the right mindset, and changing behavior of makerspace users on campus. In the study, with the help of MITOS and MIT Project Manus, we use MIT makerspace as an example to study its current status (e.g., makerspace environment and training program, the Institution's regulation, waste management system, electricity, and other utility consumption) both through qualitative and quantitative approaches to consider students/makers core needs and functional requirements for initiating an MIT circular makerspace certification checklist, educational toolkit, evaluation service, and shop experience designed for students and the community.

In studying the challenge of carbon neutrality in design education and makerspace, we found that to transform a typical makerspace into a circular makerspace we need to consider not only the fundamental criteria (e.g., material life cycle, electricity consumption, space infrastructure, and operation) but also the long-term strategies (e.g., educational purpose, business model, policy, and maker culture). Hence, we created and used CMET, an applicable framework, and suggested high-level principles and examples, to help enable the carbon neutrality action to decrease the carbon footprint in MIT makerspaces. CMET is applied to quantify, measure, and celebrate the value of circular makerspace to users/makers, and inspire them and other makerspaces around the globe to view “circular” as a new creative currency of carbon neutrality, motivating users/makers to come up with feasible plans, change their behaviors, cultivate sustainable maker culture, and make an invaluable contribution through their makerspaces to the Circular Economy.

5.2 FURTHER STUDY

We initiated and promoted CMET to transform typical makerspaces on campus into circular makerspaces by raising people’s awareness of carbon neutrality, changing people’s mindset and behavior, reducing energy, water, and material consumption, and modifying the current makerspace training program and its design education. To reach the goal of carbon neutrality in makerspaces, suggested further studies and environmentally responsible elements can be emphasized in the following three areas: 1. Validating CMET through a scientific and data-driven approach; 2. Upgrading and renovating the infrastructure of current makerspaces to capture and compare their data for analyzing with circular makerspace concept to prolong the material life cycle, foster its circulation and improve its efficiency in makerspaces; 3. Prototyping to promote the circular makerspace concept and scale its impact that can influence beyond the campus.

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